Editorial

The role of failure in promoting thinking skills and creativity: New findings and insights about how failure can be beneficial for learning

1 The pressing questions of how and why failure can be beneficial

Failure is essential to successful learning. Without failure, we cannot find out what we have not learned yet, and what aspects we might need to improve in what we are attempting to learn (e.g., Kapur & Bielaczyc, 2012; Loibl & Rummel, 2014a; Lundquist, 1999; Ziv, Ben-David, & Ziv, 2005). But all too often, failure is viewed negatively in educational settings. It is considered as something to be feared and avoided (e.g., in achievement motivation theory, failure is firmly established as a result to be avoided; Atkinson, 1957; Elliot & Church, 1997), and it is often associated with aversive outcomes and punitive consequences (e.g., Maguin & Loeber, 1996; McEvoy & Welker, 2000; McMahon, 2000). This should not be the case.

The well-known American educator and philosopher, John Dewey, has an often-cited quote that "failure is instructive". He elaborated on this to explain that a person who really thinks should be able to learn as much from experiences of failure as from experiences of success. Perhaps a case in point to support this view would be the famous inventor, Thomas Edison. He apparently accumulated a very long list of failures during his lifetime. The list included thousands of incandescent lamps and batteries that did not work as required, more than five hundred unsuccessful or abandoned patent applications, and his ultimate inability to create fuel cells (i.e., to generate electricity directly from an energy source; Simonton, 2015). Considering his better-known successes – including over a thousand patents to his name, and credit for developing the electric light bulb, the phonograph, and the movie camera – one can surmise that he managed to learn a great deal from those experiences of failure.

As educators, we have a responsibility to re-orient students as well as teachers toward a better understanding of how experiences of failure can and should be utilized in more positive and productive ways. This is easier said than done. The biggest hurdle is that, although we are not short on intuitive and common sense advice about benefiting from failure, there really is a dearth of methods and guidelines (especially ones supported by research evidence) about how exactly this can be done. For example, although teachers can encourage their students to keep trying when they fail at something, the reality is that some students will give up in spite of the encouragement. We do not sufficiently understand the factors that influence or the mechanisms that determine those differing outcomes. Likewise, in everyday life, while some of our failed efforts may clearly lead to useful lessons and more successful subsequent attempts, there are also many other failure experiences from which we apparently learn nothing – and again we are no wiser about the exact reasons for such differences.

Productive failure (PF; Kapur, 2008, 2016; Kapur & Bielaczyc, 2012) is one of a limited number of examples where a satisfactory explanation is provided for how and why failure is beneficial for learning. When using PF in instruction, students are given carefully-designed problems to solve *prior to instruction*, which leads them to experience frustration and failure in coming up with the required solutions. Instruction on the targeted concepts necessary for solving the problems is not provided until *afterward* – when the students have already made many attempts at generating solutions on their own. The important point is that using such a method has been shown to produce better learning outcomes compared to the traditional direct instruction (i.e., instruction first and then problem solving afterward). The explanation is that the initial efforts at problem solving and experiences of failure prepare students for better understanding of the corresponding concepts in the subsequent instruction (Kapur, 2012, 2016; Loibl & Rummel, 2014b). This approach of problem solving *and failing* prior to instruction lends

itself to applications in real education settings because there are clear understandable reasons for why it works, together with a set of design principles that guide its use.

There are but only a few other research findings like those of PF that lend themselves to useful educational applications. For example, Leach and Cidam's (2015) meta-analysis revealed that, although experiences of shame associated with what is perceived to be *irreparable* failure may lead to an avoidance orientation (i.e., feeling inferior and giving up), shame associated with what is perceived to be *reparable* failure more likely leads to an approach orientation (i.e., self-reproach, but also likely effort at improvement). Thus, our perception of failure influences our feelings and subsequent action. Further support comes from Bhanji, Kim, and Delgado's (2016) study, which showed that stress decreased persistence in the face of failure, but perceiving failures and other kinds of setbacks as *controllable* helped promote persistence. Again, the way failure is perceived influences subsequent behavior. Taken together, these two studies suggest the importance of cultivating a sense of causal agency (cf. Bandura, 1982) – of being able to take action and influence outcomes – if students (or people in general) are to persist in the face of failure (and hence make it possible to benefit from such experiences).

However, research reports like the abovementioned remain scarce, rendering the questions of how and why failure can be beneficial inadequately answered. This lack of answers contributes to making failure utilization simply an ideal, but not a reality in most learning environments. Our awareness of this lack provided, in large part, the impetus for instigating and compiling this special issue. We believe that failing to capitalize on a potentially beneficial learning opportunity was not desirable. At the same time, we were convinced there would be many researchers and teachers/educational practitioners who possess a great deal of knowledge, experience, insight, and research data/findings on this topic that they have yet to share. We therefore assumed the responsibility to pool this wealth of knowledge together with the aim of contributing toward making failure utilization integral to our teaching and learning practices.

2 The papers in this special issue

The 15 papers that are included in this issue can broadly be divided into two groups. The first four papers are primarily concerned with elucidating general mechanisms and processes that make failure beneficial. Key points and findings from these papers are summarized in Table 1. The remaining 11 papers describe how failure benefits and/or comprises an integral part of effective teaching and learning practices in subject-specific disciplines or learning activities. These papers also clarify important mechanisms and processes about failing and failure experiences that, in most cases, are generalizable beyond the subject domain or activity specifically dealt with in the paper. Key points and findings from these papers are summarized in Table 2.

INSERT TABLES 1 and 2 ABOUT HERE

3 Educational implications and applications

Here we briefly explain some of the important educational implications and applications we can derive from these papers. These implications are by no means exhaustive, and we encourage readers to go through the papers more carefully to obtain the respective authors' perspectives, and to develop their own views about implications and potential applications in educational contexts of interest to them.

3.1 Internal representations of failure influence responses to it.

This is a key message in the papers by Estabrooks and Couch, Fong et al., Gomoll et al., Hannigan, and Oyama et al., and it is consistent with earlier-mentioned findings by Bhanji et al. (2016) and Leach and Cidam (2015). If failure is perceived as something that can be rectified or overcome, or as a normal part of "how things are done", response to it would be more positive. This suggests the importance of cultivating metacognitive skills that would enable students to know how to

respond in possible failure situations. If they lack those requisite skills, the cognitive cost associated with efforts at rectifying or overcoming failure would likely be perceived as high and therefore prohibitive (cf. research on cognitive cost associated with spontaneous strategy use, e.g., Manalo & Henning, 2017; Manalo & Uesaka, 2012; Uesaka & Manalo, 2012). This point about how failure is perceived also suggests that we need to pay more attention to designing classroom cultural norms and values in which failure is genuinely seen *and accepted* as part of a formative process toward learning and development (Kapur & Bielaczyc, 2012).

3.2 Beliefs matter.

More specifically, from the Fwu et al. study that examined this issue, beliefs *about effort* affect attributions and emotions, and these in turn influence whether a student will persist when they fail. To put this another way, if students believe that with effort they can overcome any current limitations they may have that cause them to fail, they will be motivated to keep trying. Given that previous research (e.g., Covington & Omelich, 1984) has shown that some student groups tend to attribute failure to lack of ability and therefore are prone to giving up when they fail (to protect their self-image about their ability), this finding is critical. It suggests the usefulness of cultivating student beliefs and understanding about how effort is the major determinant of performance outcomes (and of warning them of the misconceptions about and dangers of over-reliance on "natural ability"). This view about the importance of student beliefs about effort is consistent with research findings on student *mindsets* (i.e., the implicit theories students hold), which indicate tangible advantages (better academic achievement, resilience, etc.) for students who believe their intellectual abilities and other desirable characteristics can be developed rather than being fixed (e.g., Dweck, 2006; Dweck, Chiu, & Hong, 1995; Yeager & Dweck, 2012).

3.3 External representations of failure also influence responses to it.

External representations here include how failure is framed or interpreted in the process of interacting with others (Veder-Weiss et al.), as well as how feedback about student failure or

shortcomings in their work is conveyed (Fong et al.). Inappropriate or poor representations of failure to others lead to negative responses (e.g., no resulting learning, no action toward improvement, resentment) and little or no benefit. This therefore has important implications for teacher training (see 3.5 below).

3.4 The learning environment needs to be accepting and supportive of failure.

In all the subject disciplines and learning activities that the papers included in this special issue deal with (see Table 2), environmental acceptance and support of failure is absolutely crucial. Dragan et al. even make the argument by studying the history of mathematical practice to suggest that negotiations around failure can and often did promote creative insight in mathematics. Therefore, in mathematics classrooms, opportunities should be provided for students to not only produce correct answers, but also to engage in dialogue with the teacher and other students about what constitutes correct and incorrect answers. It is indispensable for students to benefit from failure experiences in their classroom settings. Students need to be fully cognizant of and acculturated to such treatment of failure, and teachers need to be equipped with the necessary knowledge and skills for promoting the development of such environments in their classrooms. To a large extent, these would only be possible if the education system and its corresponding curricula are sufficiently flexible to allow practices for the positive utilization of failure, such as those described in the papers that comprise this issue.

3.5 Teachers need training in methods for effective failure utilization.

Following on from the previous two points, such training is absolutely vital. The teacher skills in instruction and facilitation that we get a glimpse of in the descriptions provided by the likes of Gomoll et al., and Swanson and Collins, require training and practice. Such training should be incorporated in pre-service teacher education, and provided in professional development courses for in-service teachers. Training should also be provided for teachers on effective provision of

constructive feedback (Fong et al.) to increase the likelihood that such forms of communication would be able to promote the desired learning and improvement in students.

3.6 Students need to develop skills to effectively benefit from experiences of failure.

There are numerous descriptions and suggestions in the papers contained in this issue about how such skills development can be facilitated in various subject disciplines and learning activities. Students also need instruction and/or guidance on how to interpret and respond to constructive criticism (and other forms of feedback about their work) in ways that would be beneficial to them (Fong et al.).

3.7 The benefits of failure are often indirect … and can be delayed.

Although this is not an entirely new idea (see, e.g., Kapur & Bielaczyc, 2012), some of the papers in this issue clearly demonstrate it, and we consider it useful to re-emphasize it. Failure can trigger immediate effects such as higher motivation to re-engage in or resume working on a task (e.g., Oyama at al.), but in many cases the beneficial effects are mediated by other consequences, and they may be delayed. For example, in the papers by Anderson et al., Gomoll et al., Hod et al., Searle et al., and Swanson and Collins, failure triggered discussion and collaborative problem solving, and it is through those that greater understanding, insight, creativity, and/or the generation of successful solutions followed. In the Ziegler and Kapur paper, it was not until later that better learning performance was evidenced by the students who were more creative and initially committed more errors as a consequence of that creativity. The essential lesson from this is that failure should not be a cause for alarm; it can instigate much better outcomes – but we need to be sufficiently patient, and take any necessary action to make that happen.

Acknowledgements

This special issue has only been made possible because of the generous help of many people. We would like to sincerely thank the following colleagues who freely gave of their time and knowledge to read and provide constructive comments on manuscripts during the peer review process:

Amy Ackerberg-Hastings, University of Maryland University College, USA

Maribel Blasco, Copenhagen Business School, Denmark

Marion Blumenstein, University of Auckland, New Zealand

Clark Chinn, Rutgers University, USA

Allan Collins, Northwestern University, USA

Jennifer DeWitt, University College London, United Kingdom

Toby Dragon, Ithaca College, USA

Rachel Dryer, Australian College of Applied Psychology, Australia

Michael N. Fried, Ben Gurion University, Israel

Tatsushi Fukaya, Hiroshima University, Japan

Vlad Glaveanu, Webster University Geneva, Switzerland

Judith Green, University of California, Santa Barbara, USA

Xiaoqing Gu, East China Normal University, China

Chris Hay, University of Queensland, Australia

Marcus Henning, University of Auckland, New Zealand

Cindy Hmelo-Silver, Indiana University, USA

Michael J. Jacobson, University of Sydney, Australia

Daniel Jones, University of Reading, United Kingdom

Michelle Jordan, Arozona State University, USA

Marjaana Kangas, University of Lapland, Finland

Alison Koenka, Ohio State University, USA

Christian Krägeloh, Auckland University of Technology, New Zealand

Emmanuel Manalo's work on this special issue was supported by a grant-in-aid (26285150) received from the Japan Society for the Promotion of Science.

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Table 1

Summary of key findings from the papers that investigated general mechanisms and processes that make failure beneficial

Authors	Key question addressed	Key findings
Oyama, Manalo, & Nakatani	When is failing to finish motivational?	• The closer people perceive they are to finishing a task they have failed to complete, the more motivated they would be to re-engage with the task and finish it. • People need to be able to adequately gauge what more they need to do to finish a task they have failed to complete for them to be motivated to finish it.
Fwu, Chen, Wei, & Wang	What beliefs do Asian students hold that make them persist better in the face of failure?	• When students believe in the importance of effort (for overcoming the limitations of ability, and as their role obligation), they are more likely to persist and try harder when they experience failure.
Vedder-Weiss, Ehrenfeld, Ram-Menashe, & Pollak	How can teachers benefit from pedagogical failure?	• Teacher discussion of pedagogical failures can be beneficial for learning, but only when appropriate framing or interpretation of the problem is used. • Productive framing includes acknowledging the difficulty of the teaching task and

Fong, Schallert, Williams, Williamson, Warner, Lin, & Kim	What are the requirements of effective constructive feedback?	• For feedback to be perceived as constructive and taken up by the receiver, the feedback *giver* needs to be perceived as someone who is respect-worthy and caring. • The feedback *receiver* also needs to be adequately competent in regulating the emotions and motivations that follow failure and receipt of corresponding feedback.

Table 2

Summary of key points from papers that describe how failure benefits educational practices in particular subject disciplines and learning activities

Authors	Subject discipline or activity	Key points and/or findings
Swanson & Collins	Science (middle school level)	• In class theory-building discussion, flawed initial explanations of observed phenomena form the building blocks for the development of more refined scientific explanations. • Teachers need to be able to provide appropriate guidance and allow students to refine their ideas when they fail or make mistakes (rather than simply telling them the right answers).
Ziegler & Kapur	Mathematics (primary school level)	• Students who generated more structurally creative examples made more errors and initially performed poorer in learning, but subsequently evidenced better learning. • Encouraging creativity is useful even if it may initially lead to more errors and failures, because the deeper processing and understanding that creative production requires leads to better learning outcomes in the longer term.
Trninic, Wagner, & Kapur	Mathematics	• Historical evidence suggests that, in mathematics, negotiations around failure can promote creative insight. • In mathematics classrooms, opportunities should be provided for students to not only

		produce correct answers, but also to engage in dialogue with the teacher and other students about what constitutes correct and incorrect answers.
Gomoll, Tolar, Hmelo-Silver, & Šabanović	Human-centered robotics (middle school level)	• *Formative* experiences of failure are necessary for the development of creative, collaborative problem solving skills. • Teachers need to provide *scaffolds* to orient students to the benefits of failing fast and often in collaborative problem solving environments.
Estabrooks & Couch	Inventors program (high school level)	• Young inventors learn through failure as part of the iterative and recursive nature of the invention process: they gradually develop a view of failure as part of that larger process of inventing – and *not* as an end point.
Maltese, Simpson, & Anderson	Maker education	• Maker educators employ various strategies (such as modeling troubleshooting behavior, minimizing constraints, encouraging independence and creativity in finding solutions, and reflective questioning) to increase the likelihood that failure experiences for youth would lead to persistence and gains in learning.
Searle, Litts, & Kafai	Electronic textiles design (high school level)	• In open-ended design tasks, because of the existence of multiple possible solutions, failure is always present: it is an essential part of debugging the system to identify and solve things that do not work.

Anderson, Dalsen, Kumar, Berland, & Steinkuehler	Video gaming	• Initial failures at educational game levels help to initiate collaborative discourse among players, which in turn promotes better understanding and learning of the content integrated in the game.
Hod, Basil-Shachar, & Sagy	Learning community (blended learning environment; university graduate level)	• Social failure in collaborative learning situations (e.g., communication breakdown, inability to work cohesively) leads to finding of solutions, and this in turn leads to more creative forms of collaboration (e.g., ways of working that specifically suit members of the group).
Thorley	Music (university undergraduate level)	• Instead of fearing failure in educational settings, projects that engage with failure can bring significant benefits: designing for productive failure afforded students the opportunity to develop their thinking skills and creativity in various aspects of music production.
Hannigan	Art (university level)	• For failure experiences to be beneficial, systems need to be made explicit to allow teachers, artists, and students to more clearly navigate values of success and failure that apply. • Assessment procedures that apply need to be more transparent and understandable to students (e.g., through the use of assessment rubrics).